NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

DEFENDING HIGH VALUE HOMELAND UNITS AGAINST THE LOW SLOW FLYER

by

Woodrow M. Nesbitt, Jr.

March 2004

Thesis Advisor: Thomas Lucas
Second Reader: Saverio Manago

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** March 2004	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Defending High Value Homeland Units Against the Low Slow Flyer			**5. FUNDING NUMBERS**
6. AUTHOR(S) Nesbitt, Woodrow M. Jr.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Distribution authorized to U.S. Government agencies only (Specific Authority) (23MAR04). Other requests for this document shall be referred to Superintendent, Code 0052, Naval Post Graduate School, Monterey, CA 93943-5000 via the Defense Technical Information Center, 8725 John J. Kingman Rd, STE 0944, Ft Belvoir, VA 22060-6218.			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

The Low Slow Flyer (LSF) remains a dangerous threat to critical homeland assets. In this thesis we use the Joint Conflict and Tactical Simulation (JCATS) to assess the vulnerability of the Los Angeles International Airport (LAX) to Low Slow Flyers. Our measures of effectiveness are the reaction times LAX has to defend itself against LSF threats from all directions. We find that LAX, by itself, has several vulnerabilities. By integrating LAX with a couple of well-chosen existing airport radars, in the spirit of Network Centric Warfare, we can greatly enhance the average reaction time. However, LAX still is vulnerable at certain approaches from the sea. We can eliminate this vulnerability by utilizing a Navy Guided Missile Cruiser.

14. SUBJECT TERMS Low Slow Flyer, JCATS, LAX, vulnerability, radar detection			**15. NUMBER OF PAGES** 71
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

DEFENDING HIGH VALUE HOMELAND UNITS AGAINST THE LOW SLOW FLYER

Woodrow M. Nesbitt, Jr.
Lieutenant, United States Navy
B.S, United States Naval Academy, 1997

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
March 2004

Author: Woodrow M. Nesbitt, Jr.

Approved by: Thomas Lucas
Thesis Advisor

Saverio Manago
Second Reader

James N. Eagle
Chairman, Department of
Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The Low Slow Flyer (LSF) remains a dangerous threat to critical homeland assets. In this thesis we use the Joint Conflict and Tactical Simulation (JCATS) to assess the vulnerability of the Los Angeles International Airport (LAX) to Low Slow Flyers. Our measures of effectiveness are the reaction times LAX has to defend itself against LSF threats from all directions. We find that LAX, by itself, has several vulnerabilities. By integrating LAX with a couple of well-chosen existing airport radars, in the spirit of Network Centric Warfare, we can greatly enhance the average reaction time. However, LAX still is vulnerable at certain approaches from the sea. We can eliminate this vulnerability by utilizing a Navy Guided Missile Cruiser.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

I would like to thank all of those that made my time in Monterey a success. Most importantly, I would like to thank my wife Karina for all of her support while I completed my Masters degree. I would like to thank the friends I made while completing my Masters, Levent, Mehmet, Roger, Barry, Moe, Brant, and Doug. We had a great time and supported each other through these two years. I cannot forget to thank my family back home in South Carolina.

The professors and officers of the Operations Research Department have taught and shown me things that ensured my success at NPS and later in my Naval career.

Professor Tom Lucas was a great inspiration to me from my second quarter and through the completion of my thesis. He really is “The Man”.

Lieutenant Colonel Saverio Manago, despite wearing Army green every Tuesday, was a great help with my thesis. You pushed me to tackle JCATS and complete my thesis. I am sorry we couldn’t shoot ‘em down.

And I would kick my own butt if I left out Ed Nath. Ed was always there for my JCATS troubleshooting. Thank you Ed.

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Recent years have shown that the only Super Power in the world, the United States, is vulnerable within its own borders to terrorist attack. With this vulnerability, the U.S. military must step up its theories and practices on the home front. One particular threat that has not gone unnoticed is the Low Slow Flyer (LSF).

There is an imminent threat of LSFs towards our military and civilian populations. There exists a concern that the military is no longer the target of attacks, but that the civilian population is well within the reach of terrorists. There is a need for military assets to protect our citizens against these terrorist threats within our borders.

Los Angeles International Airport (LAX) is a prime target for terrorists due to the public sensitivity and potential damage it would cause. This study models the capability of defending LAX against a LSF using multiple radar sensors currently in the vicinity of Los Angeles, and bolstering the defense measures by adding an AEGIS Missile Cruiser.

Our threat is the Low Slow Flyer since it is readily accessible to terrorists. The LSF is also a viable threat because the low altitude masks the threat from radars and its low speed allows the aircraft to follow the contours of the land. These two characteristics combine to allow the threat to be undetected until it is in close proximity to its target. Traveling on civilian air routes and because the LSF is widely used by the civilian populous also make

them a potential terrorist threat because they blend in with normal civilian air traffic.

Our measure of effectiveness is the reaction time allowed to LAX based on the detection ranges from all resources. The detection range is the 95% lower bound from multiple sensors. Our goal is to maximize the available reaction times. This study aims to quantify the potential advantages of interconnectivity of airport radars in the Los Angeles area and the supplemental value of Navy assets, such as an AEGIS Cruiser. We will use the Joint Conflict and Tactical Simulation (JCATS) to calculate our measure of effectiveness with the Los Angeles International Airport as the target.

LAX had two weaknesses in its detection contours due to landmasses obstructing the ability of the radar to detect the threat. We created a network of shared radar data by adding sensors to increase the detection ranges. The network of radars is able to cover the dead space not covered by the LAX radar. In Table 1, you can see the value of adding resources to support LAX. The LAX values show a weak point in which there is only 5 minutes for reaction. Once sensors are networked the slowest reaction time is more than doubled to over 12 minutes of reaction time. Table 1, below, shows the gain by networking sensors in the Los Angeles Area.

	LAX		Recommended	
	Range (km)	Time (min)	Range (km)	Time (min)
Average	43.12	12.83	97.35	28.97
Minimum	17.36	5.17	42.23	12.57

Table 1. Advantage of Adding Resources

Figures 1 and 2 below show the corresponding 95% lower confidence bounds for the two instances shown in Table 1 as the black line around LAX. Visually the advantage of networking the radar systems becomes obvious with the differences in the two figures.

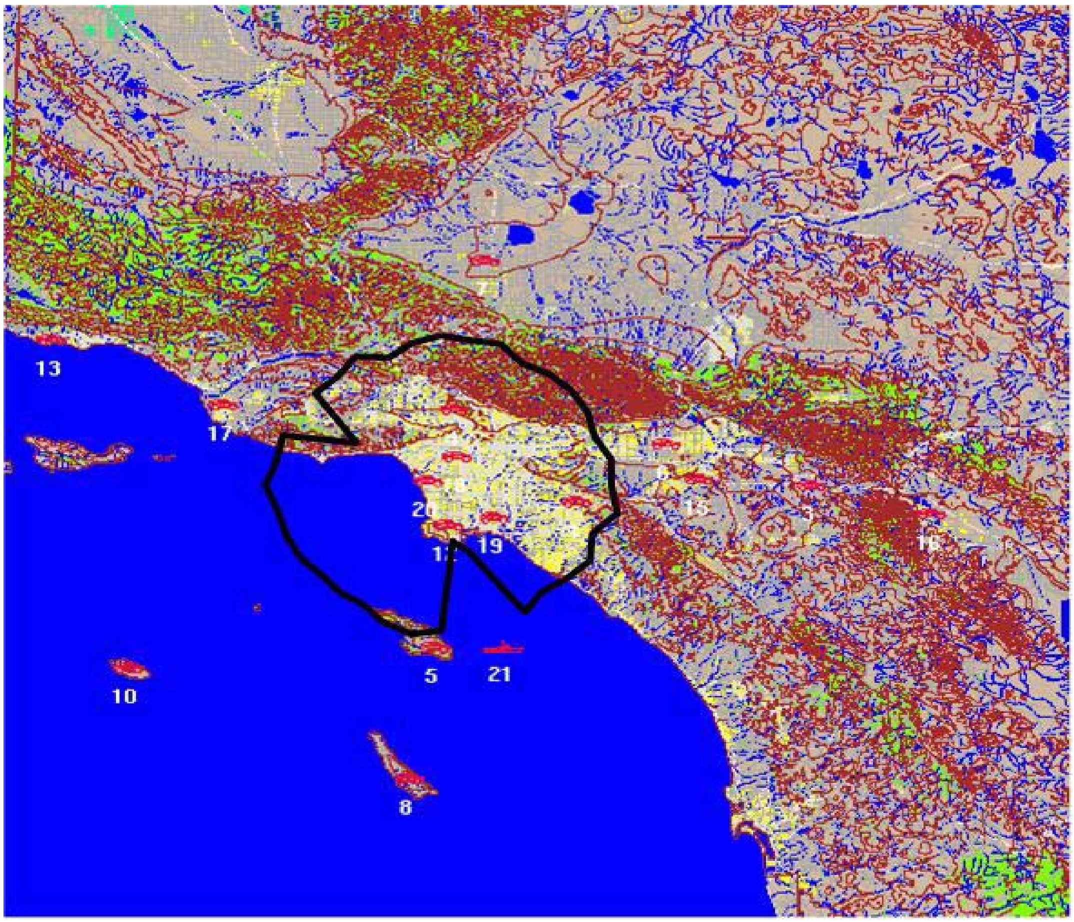

FIGURE 1. LAX Without Networking

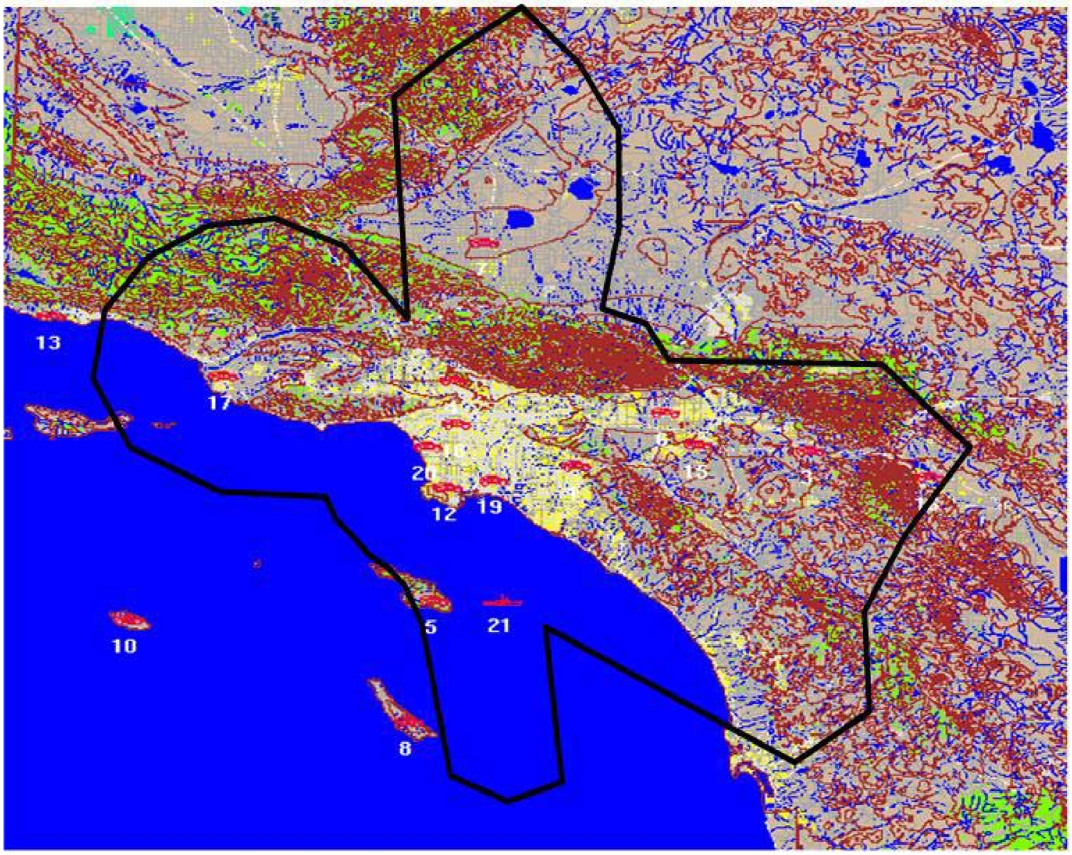

FIGURE 2. LAX With Networking (LAX, 4 other civilian radars and an AEGIS Cruiser)

I. INTRODUCTION

A. INTRODUCTION

In recent years the Homeland Security Council has been building momentum to bolster the domestic defense of the United States. The attack on USS COLE and the events that occurred on September 11, 2001 led to the conception of the Homeland Security Council. These attacks caused feelings of vulnerability to increase within the nation. The military has stepped up its self-defense measures throughout the nation. However, one area that still requires improvement throughout the military and especially in the vicinity of naval harbors, like Los Angeles, is air defense against Low Slow Flyers (LSFs).

Currently there is an imminent threat of LSFs towards our military and civilian populations. The Air Force and Army continue to lead among military services in regards to the theories and practices of area air defense. A program must be implemented for the Navy to strengthen the defense of naval harbors and bases against this threat. There is a growing concern that the military is no longer the target of attacks, and that the civilian population is in need of military assets for protection against these terrorist threats.

This thesis will define a current threat to US National Security and aid in the development of programs, methods, and deployment of resources against Low Slow Flyers in order to maximize reaction time and ultimately lead to the destruction of these threats.

B. BACKGROUND

As previously mentioned, the Army and Air Force currently practice similar air defense practices. The Patriot Missile System, MANPADs, Stinger Missiles, and other resources currently exist for area air defense. Some considerations to take into account would be ease of training Navy personnel, availability of weapons, placement of weapons, and mobility.

The threat of Low Slow Flyers has not gone unnoticed, but has been unchallenged. On September 11, 1994 a single engine Cessna crashed into the White House with no early warning. When asked how much reaction time was offered, a Secret Service Agent replied, "I think enough time to run for cover." This is an amazing amount of time given that National Airport had radar contact on the aircraft minutes before the crash. In this case the plane disregarded all Federal Laws that prohibit flying over or near the White House. The Cessna flew in unchallenged.[1]

In January 2002 in Tampa, Florida, a 15-year-old pilot disregarded Coast Guard helicopter warnings and flew a Cessna into a skyscraper. This case occurred post 9/11 and in the same city as the Central Command. Again, air-traffic controllers at St Petersburg-Clearwater Airport noticed the Cessna had taken off without clearance. Two F-15s were scrambled as a precautionary measure but it is unknown if they reached the Cessna before it crashed into the 40 story Bank America building.[2]

---

[1] Radar Detected Airplane Before White House Crash, Ruben Castaneda and Pierre Thomas, The Washington Post, September 13, 1994.

[2] Tampa crash raises serious security questions, www.cnn.com, CNN, January 6, 2002.

These two cases occurred despite defensive measures. And, the 15-year-old pilot was successful in causing terror in the post 9/11 era with the current defensive measures in place. The threat of a Low Slow Flyer is now on this side of the horizon.

C. PROBLEM STATEMENT

The United States has many enemies that use unconventional means to achieve their objectives. One threat the Navy must bolster its defense against is the threat of Low Slow Flyers. Low Slow Flyers are cheap, in regards to both cost and deployment methods, and can be launched from many low security areas.

To aid in the development of air defense methods, we researched resources and conducted combat simulations to assist in the connectivity of resources currently in place in Los Angeles, as well as the additional placement of military resources to key strategic positions. We concentrated this thesis on the Los Angeles area, but the method used in this study can be applied to any area of concern where LSF terrorist threats are probable.

The first step is to define the threat. Low Slow Flyers (LSFs) are a main air threat to targets within the national borders as well as our Naval Bases. The low altitude masks the threat from radars and the speed allows the LSF to follow the contours of the land. These two characteristics combine to give little to no time to act in self-defense. Traveling on civilian air routes and because the LSF is widely used by the civilian populous also make them a potential terrorist threat because they blend in with normal civilian air traffic. LSFs have many forms, helicopters, privately owned airplanes (Piper Cubs, Cessnas, etc), and unmanned aircraft. The majority of attacks from LSFs would be suicide missions, with payloads consisting of explosives, chemical weapons, or perhaps even nuclear weapons. Future threats from terrorists could also consist of unmanned aircrafts (UAVs) carrying weapons payloads as previously mentioned. These UAVs may pose a more dangerous threat since they do not need airport facilities to be launched against their target.

D. MEASURE OF EFFECTIVENESS

Our measure of effectiveness is the aspect dependent reaction time. Visually, this closely resembles a cookie cutter radar detection ring, but with a slight change due to the effects of the land elevation that will alter the detection radius. The measure of effectiveness is the detection radius calculated from the 95% lower bound of the detection ranges from multiple sensors. Then, we will calculate the reaction times the high value target will have for evacuation and/or self-defense. Our goal is to maximize the available reaction time. This study aims to quantify the potential advantages of interconnectivity of airport radars in the Los Angeles area as well as the proper placement for military sensors to achieve the largest reaction times and also to show how vulnerable Los Angeles International Airport may be to an attack from a Low Slow Flyer. We will use the Joint Conflict and Tactical Simulation (JCATS) to calculate our measure of effectiveness with the Los Angeles International Airport as the target.

LSFs have extremely high potential for causing damage, therefore early warning is a primary goal in this research.

New radar systems or new implementations of current radar systems are essential for the success of self-defense.

THIS PAGE INTENTIONALLY LEFT BLANK

II. JOINT CONFLICT AND TACTICAL SIMULATION

Reaction times are calculated using the Joint Conflict and Tactical Simulation (JCATS). For more information on JCATS, visit http://www.jwfc.jfcom.mil/. JCATS is currently used throughout the Department of Defense (DoD) and many other U.S. government agencies. JCATS was developed at Lawrence Livermore National Laboratory and its uses include:

- Training (individuals, staffs, command elements)
- Analysis (weapons, force structure, tactics)
- Planning (course of action analysis)
- Mission Rehearsal (coordination and timing)

JCATS was chosen for the simulation because it is widely trusted throughout the Department of Defense. JCATS is considered a valid modeling resource due to its applications to current and future military projects.[3]

A. WHY JCATS

JCATS evolved from a merger of the Joint Tactical Simulation (JTS) and the Joint Conflict Model (JCM). JCATS is a real-time, stochastic, multi-sided, high resolution, entity level, and interactive combat simulation model. It is used to model strategic situations through tactical levels across the broad spectrum of war. It models engagements from the Joint Task Force level to individual conflicts in Military Operations-Other-Than-War.

[3] The Joint Conflict and Tactical Simulation (JCATS) Overview Slide Presentation, Tom Mcgrann, Lawrence Livermore National Laboratory, July 9, 2003.

The high-resolution nature of JCATS allows the analyst to control the inputs and actions for individual systems in a scenario. Analysts are able to direct movement and activities of the systems and units under our control through the model environment with pre-planned routes.

JCATS uses DOD validated acquisition algorithms to determine if detection occurs and checks the terrain and visibility parameters for influence that may hinder detection. Combat between systems/units in JCATS is based primarily on line of sight (LOS) and signal strength. Our targets typically have a high radar cross section, thus LOS drives our problem. Line of sight involves the threat altitude and the sensor height. Due to the curvature of the earth, a threat at low altitudes will remain undetected until is comes over the horizon. The other influence in detection is if the threat is masked by landmasses. JCATS algorithms 1) check if the threat is within the radar LOS with sufficient signal strength and 2) checks if there are any landmasses or buildings that will mask the threat from detection. The radar range equation algorithms have been validated and verified to be accurate.[4]

$$RHR_k = 4.12\left(\sqrt{h} + \sqrt{a}\right)$$

Where RHR(k) is the radar horizon range in kilometers, h is the known antenna height(meters), and a is the known threat altitude(meters).

The environment for the model consists of a terrain file representing the Los Angeles harbor and the surrounding area. This terrain file was created from elevation data obtained from the National Imagery and

[4] Support of JCATS limited V and V, James G. Taylor and Beny Neta, September 2001, Naval Post Graduate School

Mapping Agency, www.nima.mil, linked with the United States Joint Forces Command in the form of Digital Terrain Elevation Data (DTED). The terrain file can be set to any resolution desired, but the higher the resolution is, the larger the file is. The resolution for this scenario has the contours set to every 100 meters. The file covers a 400km x 400km area.

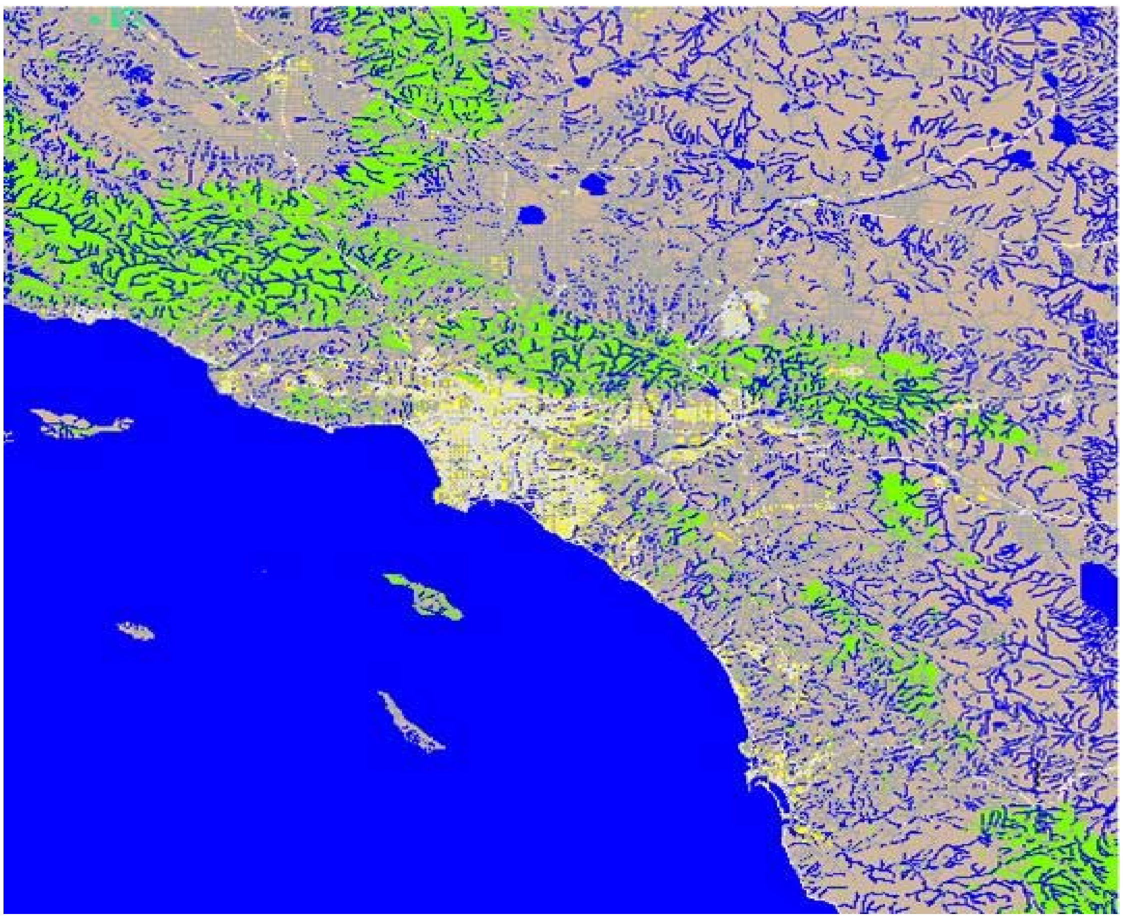

FIGURE 3. Los Angeles Terrain File (best viewed in color)

B. KEY FUNCTIONS OF JCATS

Some of the most important features and capabilities of JCATS that were used in our scenario are:[5]

[5] Lawrence Livermore National Laboratory, JCATS Simulation Guide, Livermore, CA, 1998

- Platforms blocking Line of Sight (LOS)
- Four levels of aggregates: ground, fixed wing, helicopter, and water.
- Peripheral acquisitions
- Detailed trafficability model

These JCATS features, paired with appropriate technical data and tactical inputs, can be combined to simulate operations and tactics of a given force.

The algorithms in JCATS are comparable to those of other contemporary, high-resolution Monte Carlo combat simulations (e.g., JANUS ARMY) and therefore adequate for analysis of issues concerning, for example, long and short range sensor detection of Low Slow Flyers.[6]

C. BOUNDS AND LIMITATIONS OF JCATS

Due to the JCATS database having set entities, we were forced to alter flight characteristics of a Globalhawk Unmanned Air Vehicle so that its flight characteristics fit those of a LSF threat (Flight path altitude = 100 meters, velocity = 110 knots). The choice of using the Globalhawk to represent the threat was based on flight characteristics and radar cross section. The Globalhawk is comparable to the size of a Cessna or other civilian aircraft. The flight altitude and speed were altered to represent the LSF threat desired for simulation. JCATS is very versatile in that the systems and units in JCATS can be altered to many platforms that are not listed in the JCATS database. The main drawback to this is that it takes time to build platforms that do not exist in the JCATS database. One way to counter this is to alter a current entity in JCATS and provide it with current performance attributes through the

[6] Support of JCATS limited V and V, James G. Taylor and Beny Neta, September 2001, Naval Post Graduate School

use of JCATS VISTA. VISTA is the scenario editor’s tool in JCATS. Through the use of VISTA we are able to change the profiles and characteristics of any entity. An operator can also alter sensor and system characteristics.

THIS PAGE INTENTIONALLY LEFT BLANK

III. SCENARIO

A. HIGH VALUE UNIT

Los Angeles International Airport (LAX) is the high value unit that is the basis for protection in this thesis. LAX was chosen as the high value unit because of its close proximity to the harbor and due to its high value as a terrorist target. LAX is a likely terrorist target because of its high visibility and mass confusion potential if a threat were realized. LAX was chosen in a recently foiled bomb attack because it was “sensitive both politically and economically”.[7]

B. LOW SLOW FLYER THREAT

The chosen threat is a low slow flyer. Sgt John Sullivan, a member of the Los Angeles Sheriff’s Department, feels the LSF threat is very viable in today’s war on terrorism. The capabilities and options afforded a terrorist with a low slow flyer are highly numbered and versatile. A low slow flyer threat can come in the form of a small civilian airplane, such as a Cessna, that can take off from small, unmonitored airfields, to a UAV armed with explosives and launched from small open areas. Potential uses of low slow flyers are limited only by the imagination. Some possible scenarios include suicide missions into air control towers and other superstructures of importance, and a bolder mission of intercepting a large internationally bound flight while taxiing on the runway. The takeaway is that the low slow flyer is a viable threat

[7] Terrorist reveals why he choose LAX to bomb, July 6, 2001, Phil Hirschkorn, http://www.cnn.com/2001/LAW/07/05/millennium.plot.trial/.

because of ease of acquirement and high potential of damage.

The idea is that a low slow flyer can conduct a surgical attack by flying below radar coverage. In this scenario, we assume the threat will travel in a straight flight path vice a flight path that follows the contours of the land. Given the low altitude flight path and the inconsistent ground levels, the land itself will prove to be the greatest hindrance to radar detection.

Using the current radar placements, the LSF threat was flown in straight-line paths from an originating point outside of radar coverage directly into LAX. The LSF flew 36 different routes, spaced 10 degrees apart, completing the full 360-degree coverage. Each route was also run 10 times in order to calculate statistical data to support the research.

C. DETECTION FORCES

The blue forces in the scenario, are modeled by placing equivalent air defense radar systems at airport latitudes and longitudes that are currently in the greater Los Angeles Area, see Table 2. The analysis revealed that these radars left gaps from the sea. Therefore, additional radars were placed on the three main islands off the coast of Los Angeles to see how much value they could be to overall threat detection. A single Guided Missile Cruiser was also used in the scenario for increasing the detection range from an ocean-originated attack. We are assuming that the radar cross-section of the threat is strong enough to give all radar systems equivalent detection capabilities. The radars contribute early warning alerts to LAX. It is also feasible to place air defense weapon systems to eliminate the threat once detected. However, in this study, eliminating the threat was not modeled.

Station	Latitude	Longitude
Anaheim	33.51.53	117.50.33
Beaumont	33.55.47	116.57.54
Burbank Valley Pump Plant	34.11.00	118.20.00
Catalina Airport	33.24.18	118.24.57
Fontana Kaiser	34.05.00	117.31.00
Lancaster	34.44.00	118.12.00
Long Beach	33.48.42	118.08.47
LAX	33.56.17	118.24.20
LA Downtown USC	34.01.40	118.17.45
Oxnard (Camarillo)	34.11.53	119.10.31
Palm Springs	33.49.39	116.30.35
Riverside FS	33.57.04	117.23.16
Santa Barbara	34.25.33	119.50.33
Torrance	33.48.06	118.20.28

Table 2. Airport Latitudes and Longitudes[8]

[8]http://www5.ncdc.noaa.gov/climatenormals/clim20-02/NWS_SNOW_NDYFXX_fmt.dat.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. ANALYSIS METHODOLOGY

A. STRATEGY

To promote security against a LSF threat in today’s war on terrorism, potential targets must be prepared for defense. Each metropolitan area is a potential target, and has resources that can be valuable to threat detection. Airport radars are the best resource to detect Low Slow Flyers currently in place. A network consisting of shared data from radars in the vicinity of a targeted area would improve reaction times.

The scenario in the Joint Conflict and Tactical Simulation (JCATS) models radars or sensors placed at positions that represent the 15 airports in the greater Los Angeles Area. This combat simulation is then run using a port in the Los Angeles Harbor and the surrounding areas to Los Angeles International Airport (LAX).

It must be understood that we only model for a single measure of effectiveness. All recommendations will be based on the reaction time given to a high value target, which is our measure of effectiveness. We display the measure of effectiveness through tables and graphs that show the effectiveness of the number of sensors and the location versus the gained coverage area. We look at the maximized minimum lower bound of detection range (i.e., reaction time), and the maximum average detection range of all radars used in each scenario run.

The model will show weaknesses and potential avenues a threat LSF may take to get as close as possible to the high value target, thereby causing the most damage due to the lowest reaction time. Based on the calculated reaction times, we identify the most effective supporting civilian radars to be networked with LAX. Any major weaknesses that are not covered by supporting airport radar coverage will then be compensated for with the addition of military sensors to extend the detection range for a greater MOE. We use visual radar range detection images as a decision making tool in choosing sensors for data sharing.

1. Situation

The runs were conducted using a LSF attacking LAX from varying degrees. Attacks were run originating from outside sensor range from every ten degrees and at a flight altitude of 100 meters. FIGURE 4 shows the orientation used when setting the routes for attack with bearing 000 oriented to the north. Flight altitude was set at 100 meters in order to ensure the threat would be below the land contours. The contours in JCATS terrain file are set at 100 meters for the same reason. These contours can be seen in a color representation of FIGURE 4. The speed of the threat was set at 110 knots, which is comparable to a common velocity for small civilian aircraft. Sensors were placed at latitudes and longitudes of existing airport radars in the Los Angeles area. Given the high value area, all detection ranges were calculated from the latitude and longitude of LAX. These ranges were then analyzed to find the minimum number of radars that provide the greatest detection ranges based on our MOE. With sensors in place, we flew the low slow flyer towards the high value target, varying the route by 10-degree increments until we have used all 360 degrees. The LSF attacked from low altitudes only, since this is the most dangerous enemy course of action. The low altitude also ensures that the reaction time is at least as good as the reaction times at higher altitudes. These values are plotted on maps of the area showing the detection ranges.

Radar Label	Airport	Latitude	Longitude
1	Anaheim	33 51 53	117 50 33
3	Beaumont	33 55 47	116 57 54
4	Burbank Valley	34 11 00	118 20 00
5	No airport		
6	Fontana Kaiser	34 05 00	117 31 00
7	Lancaster	34 44 00	118 12 00
8	No airport		
10	No airport		
12	Torrance	33 48 06	118 20 28
13	Santa Barbara	34 25 33	119 50 33
15	Riverside	33 57 04	117 23 16
16	Palm Springs	33 49 39	116 30 35
17	Oxnard	34 11 53	119 10 31
18	LA Downtown USC	34 01 40	118 17 45
19	Long Beach	33 48 42	118 08 47
20	Los Angeles International	33 56 17	118 24 20
21	Guided Missile Cruiser	33 19 17	118 04 40

Table 3. Airport Labels and Positions

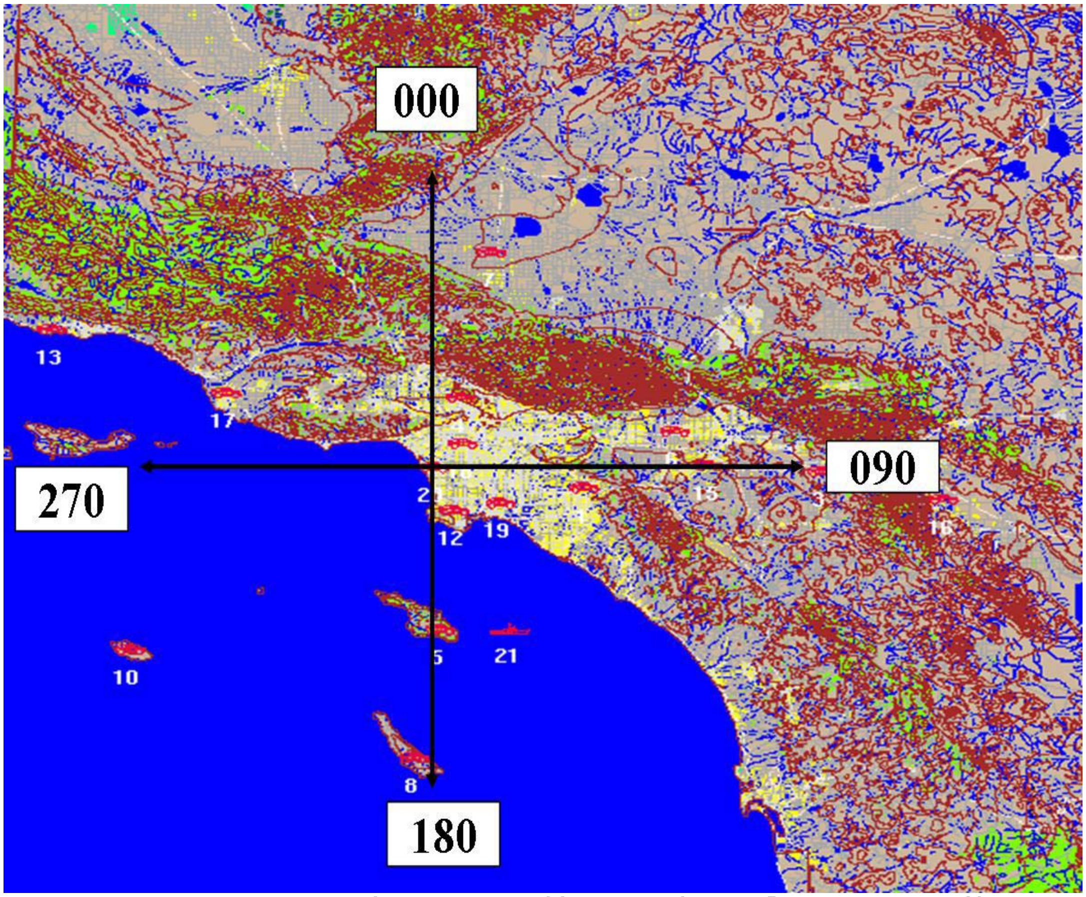

FIGURE 4. LAX and Surrounding Radar Placements (best viewed in color)

2. Ship Affect

A weakness was observed in the attack angles originating from the sea. This weakness is due to the low altitude of the aircraft and the physical features of the land that limit radar coverage. This weakness can be strengthened with the placement of an AEGIS Cruiser (or other Navy and Coast Guard assets) in the alley of the weak detection. An AEIGIS Cruiser was placed along the bearings in which the reaction time was effectively lowered to less than 6 minutes. The AEGIS Cruiser is then able to lengthen the reaction time sufficiently enough to allow for a more complete radar coverage against the low slow flyer. Due to the limited resources available for detection to the seaward side of the target, a ship is a valuable asset to accomplish extended range detection. Other options used were adding radars to islands to further extend radar coverage to the sea, however not all harbors allow for island placed radars. Not modeled with this scenario, there would also be assets available to a CG or equivalent ship consisting of weapons to destroy the target once detected, as well as a helicopter detachment to extend radar coverage over the horizon.

3. Most Likely Course of Action

There are currently over 40 airfields within 300 miles of the high value target.[9] For this scenario only those radars and airports within the greater Los Angeles Area were used, these radars can be seen in TABLE 3 with their corresponding latitude and longitude. These airfields are considered as one of the most likely launch areas for any terrorist attack if a small civilian aircraft conducts the attack. The position of these airfields allow for any straight-line route of attack to be taken for an attack on LAX. Simulations are run using these routes. The detection ranges and reaction times from each simulation run are recorded and analyzed. Once these values are recorded we can provide recommendations for which radar locations are the most valuable in terms of gaining reaction time. Security at all airfields must be increased in order to avoid an attack from a local airfield. An attack from a local airfield would mean that the threat is never detected outside of LAX vicinity since the attack would originate at such a close proximity to its target

[9] http://www5.ncdc.noaa.gov/climatenormals/clim20-02/NWS_SNOW_NDYFXX_fmt.dat.

that reaction time would then be a negligible measure of effectiveness.

B. MEASURES OF EFFECTIVENESS

The measure of effectiveness will be equivalent to an altered cookie cutter model due to the effects from changes in elevation that alter the detection radius. The actual measure of effectiveness is the reaction time that is afforded LAX for an incoming attack. To calculate this MOE, the detection radius from Los Angeles International Airport is converted from a distance in kilometers to a time in minutes. The Low Slow Flyer will travel at a constant speed of 110 knots. The LSF travels at 110 knots because that is a common flight speed of civilian aircraft. This speed was used to calculate all reaction times. The reaction times will change inversely with a change in speed. This study will show the advantages of a communication network of radar systems at each airport in the area. We will utilize the sensors to achieve the longest reaction times as well as to show how vulnerable the Los Angeles International Airport may be to attack from a low slow flyer threat.

C. ASSUMPTIONS

There are some key assumptions made to conduct this study.

1. JCATS

These assumptions are made concerning the combat simulator used to gather the statistical data of the detection of the Low Slow Flyer threat by the airport radar systems.

a. The Accuracy of JCATS

An assumption was made as to the accuracy of JCATS to conduct realistic simulations with accurate and realistic results. The DOD trusts JCATS accuracy, as previously mentioned.

b. JCATS Systems and Sensors

An assumption was made as to the realistic representation of the sensors and systems that were used in this combat simulation. We verified the radar performance and LSF characteristics to be an accurate representation of real world entities. The enemy Low Slow Flyer was assumed to have the same flight characteristics as a Globalhawk UAV. The LSF was also assumed to have a large enough radar cross section so that all air defense radars have equal detection performance. That is, at the ranges we looked at once the LSF was unobstructed the radars could detect it with high probability. We assumed the airport radar systems have the same detection characteristics as the JCATS Air Defense Radar system.

2. Low Slow Flyer

These assumptions were made concerning the performance of the enemy Low Slow Flyer threat.

a. The Low Slow Flyer Travels In a Straight-line

The Low Slow Flyer was assumed to travel in a straight line along a single line of bearing from LAX. This assumption was made due to the infinite number of possible routes that can be taken by the enemy threat. Due to the contours of the land in the vicinity of LAX, an enemy aircraft could possibly remain undetected until it arrives in the open spaces around LAX giving less than 10 minutes of reaction time.

b. The Low Slow Flyer Travels with the Contours

Due to the nature of a Low Slow Flyer, such a threat will travel below radar coverage when possible by following the contours of the land. The hills around LAX actually support in the detection of threats since the threat must fly above the radar horizon at certain distances.

3. Radar Sensors

These assumptions were made concerning the intercommunication of all radar systems in the vicinity of LAX.

a. All Radar Systems Share Data

All radar systems have a full account of all detection data of each radar system. This assumption is akin to that of an omniscient presence that can see what all systems see. The assumption of Network Centric Operations is critically important to extending the detection ranges and the reaction times.

b. Radar System Characteristics

All radar systems have the same detection characteristics. All radars have the same power and can detect the same signal strengths of threats. In JCATS, the detection range for each radar is set to 50,000 kilometers. 50,000 kilometers was chosen because it is large enough to detect the threat at a low altitude based on line of sight characteristics.

c. All Radars Have the Same Capability

All radars have the same detection capability and are susceptible to the same interference and masking of the threat.

V. RESULTS

A. DATA COLLECTION

Data collection was accomplished by running 10 Monte Carlo batch runs at each route of attack. The outputs of these 10 runs were then placed in EXCEL and the average and lower confidence bounds were calculated. The lower confidence bounds on the average detection range were used because we are concerned with the worst-case scenario from each attack route.

$$95\%LowerBound = \bar{X} - t_{.05,9}\left(\frac{s}{\sqrt{10}}\right)$$

Where $\bar{X}$ *is the average of 10 simulation runs and s is the sample standard deviation.*

Each radar placement was calculated with a distance to LAX. This distance was then converted to a reaction time using the following equation.

$$DETECTIONRANGE(km) = \sqrt{\left((y_{detect} - y_{LAX})^2 + (x_{detect} - x_{LAX})^2\right)}$$

The detection range is calculated in kilometers. The x and y coordinates are both calculated from the JCATS grid, which is in kilometers.

$$REACTIONTIME(\min) = \left(\frac{DETECTIONRANGE}{V_{LSF}} * 60\right)$$

The Reaction time is calculated from the above detection range and the speed of the LSF(V_{LSF}) in kilometers/hour. See tables 4 and 5 for the detection ranges and reaction times for LAX without any other radars networked.

1. LAX Data

First we looked at the detection ranges from LAX using only itself as a radar resource. Looking at the data gathered, there is a huge weakness coming from the 160-170 routes and from 300. These two areas where there is a huge drop off in detection range are attributed to land masses that mask the enemy threat as it approaches the target. Therefore, radar sensors must be placed for detection. One other note is that we would like to increase the ranges throughout all potential routes. 45 kilometers traveling at 110 knots gives a reaction time of approximately 14 minutes. The data from TABLE 4 is explicitly shown in FIGURE 5, with the dark circle representing the detection ranges.

Direction	Detection Range (km)	Direction	Detection Range (km)	Direction	Detection Range (km)
000	46.59	120	46.39	240	44.27
010	45.76	130	44.53	250	44.73
020	46.77	140	42.53	260	45.01
030	43.78	150	45.09	270	47.78
040	45.20	**160**	**21.86**	280	45.36
050	45.90	**170**	**17.36**	290	45.82
060	45.65	180	44.71	300	26.54
070	44.13	190	46.59	310	44.63
080	46.75	200	45.13	320	43.97
090	46.01	210	42.53	330	46.32
100	48.40	220	42.95	340	42.23
110	43.52	230	42.69	350	45.01

Table 4. Detection Ranges (Lower Bounds) for LAX

Direction	Reaction Time(min)	Direction	Reaction Time(min)	Direction	Reaction Time(min)
000	13.86	120	13.81	240	13.17
010	13.62	130	13.25	250	13.31
020	13.92	140	12.66	260	13.39
030	13.03	150	13.42	270	14.22
040	13.45	**160**	**6.51**	280	13.50
050	13.66	**170**	**5.17**	290	13.63
060	13.58	180	13.30	**300**	**7.90**
070	13.13	190	13.86	310	13.28
080	13.91	200	13.43	320	13.09
090	13.69	210	12.66	330	13.78
100	14.40	220	12.78	340	12.57
110	12.95	230	12.70	350	13.39

Table 5. Reaction Times (Lower Bounds) for LAX

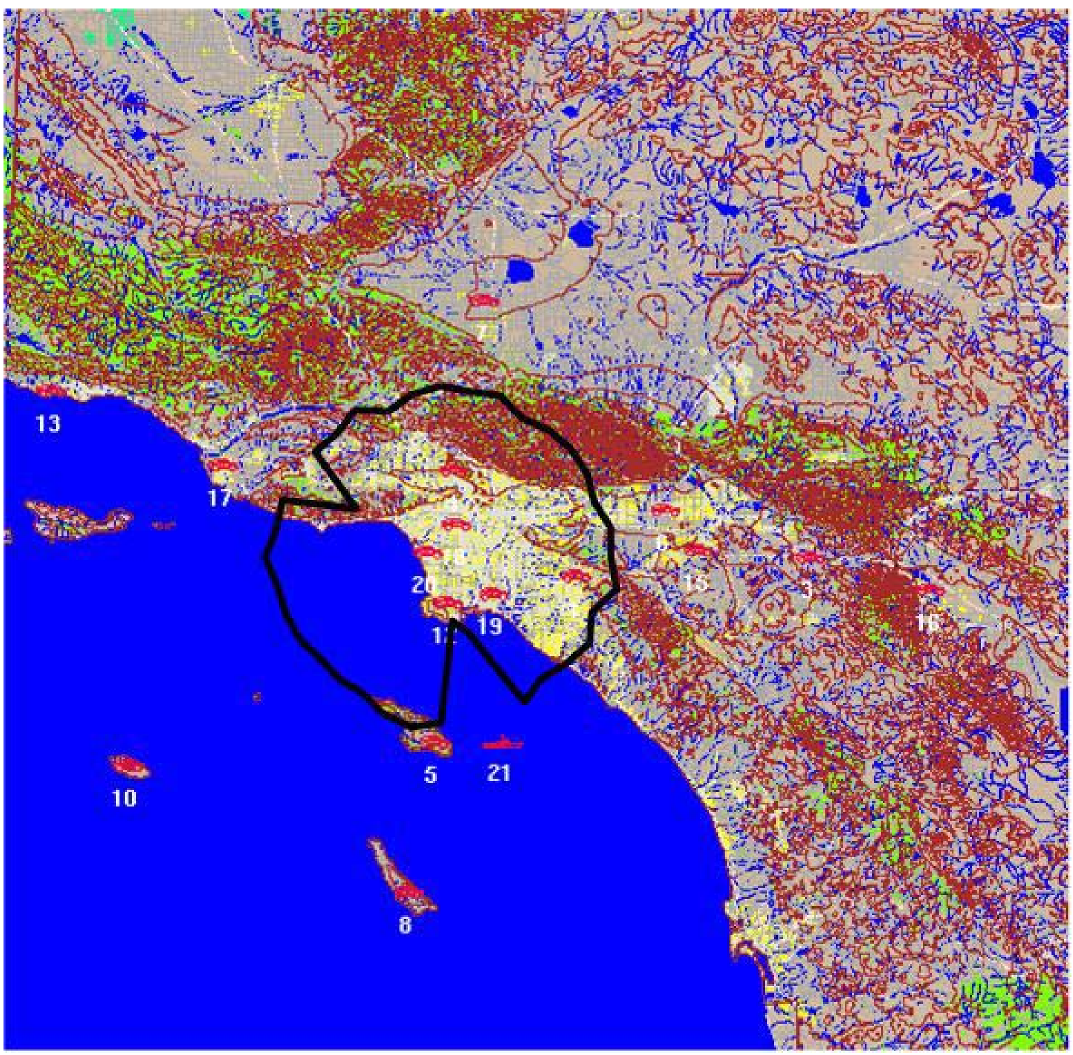

FIGURE 5. LAX Radar Ranges (best viewed in color)

The LAX data shows that there are two areas that give a very small reaction time, as mentioned below. The best we could ask for in this case was a little over 5 minutes reaction time.

2. Selecting the Best Radar with LAX

We now look at which existing airport radar system would give LAX the greatest additional benefit. We looked at two possible ways to measure the MOE. One would be to give the highest overall average of reaction times using the lower bounds. The second method used the radar that provided the highest reaction times when looking at the minimum times from all of the routes flown by the LSF. These correspond to a well-planned and more random terrorist attack. TABLE 6 shows the corresponding lower bounds with LAX's radar supplemented with only one other radar.

RADARS	detection(km) average	detection(km) minimum	Reaction Times(min) Average	minimum
LAX	43.12	17.36	12.83	5.17
LAX,1	54.66	**19.90**	16.27	**5.92**
LAX,3	**61.52**	17.36	**18.31**	5.17
LAX,4	44.76	17.36	13.32	5.17
LAX,5	44.92	17.36	13.37	5.17
LAX,6	52.65	17.36	15.67	5.17
LAX,7	56.12	17.36	16.70	5.17
LAX,8	54.70	17.36	16.28	5.17
LAX,10	51.51	17.36	15.33	5.17
LAX,12	45.47	17.36	13.53	5.17
LAX,13	49.28	17.36	14.67	5.17
LAX,15	53.18	17.36	15.83	5.17
LAX,16	59.91	17.36	17.83	5.17
LAX,17	56.26	17.36	16.74	5.17
LAX,18	47.04	17.36	14.00	5.17
LAX,19	47.99	17.36	14.28	5.17

Table 6. LAX with Single Radar Detection Data

a. Highest Overall Average

To gain the highest overall average detection time, LAX radar should be supplemented with Radar 3, which is the radar located in Beaumont, CA, as seen in TABLE 6. This may be deceiving in that this radar is located east from LAX. Adding Radar 3 does not increase the lowest reaction time; however it does increase the eastern ranges by a large margin. This skews the average; however we can see that there is a benefit from adding Radar 3. The main problem is that it does not solve the problem that we have with only LAX as our sensor. The weakness still remains at bearings 160, 170, and 300, as seen in TABLE 7 below and in FIGURE 6.

direction	LAX range	LAX,3 range	direction	LAX range	LAX,3 range	direction	LAX range	LAX,3 range
000	46.59	46.59	**120**	**46.39**	**162.50**	240	44.27	44.27
010	45.76	45.76	**130**	**44.53**	**150.76**	250	44.73	44.73
020	46.77	46.77	140	42.53	42.53	260	45.01	45.01
030	43.78	43.78	150	45.09	45.09	270	47.78	47.78
040	45.20	45.20	**160**	**21.86**	**21.86**	280	45.36	45.36
050	45.90	45.90	**170**	**17.36**	**17.36**	290	45.82	45.82
060	45.65	45.65	180	44.71	44.71	**300**	**26.54**	**26.54**
070	44.13	44.13	190	46.59	46.59	310	44.63	44.63
080	**46.75**	**147.13**	200	45.13	45.13	320	43.97	43.97
090	**46.01**	**174.49**	210	42.53	42.53	330	46.32	46.32
100	**48.40**	**154.99**	220	42.95	42.95	340	42.23	42.23
110	**43.52**	**147.89**	230	42.69	42.69	350	45.01	45.01

Table 7. Reaction Times with LAX and the Beaumont Radar(3)

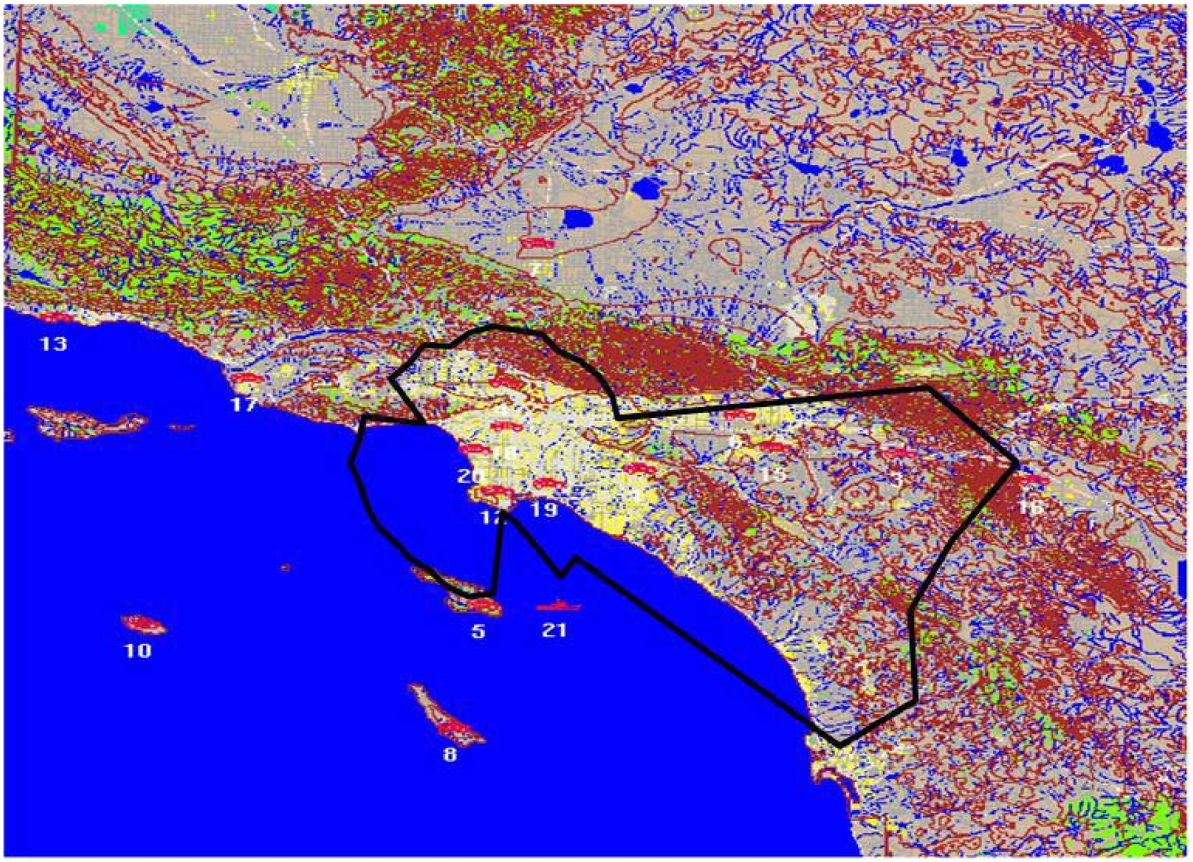

FIGURE 6. LAX Radar with Beaumont Radar (3)

b. Highest Minimum Reaction Time

To achieve the highest minimum reaction time we would add Radar 1, which is located in Anaheim, CA, taken from TABLE 6. We can see that the radar coverage minimum detection range increases from 17.36 kilometers to 19.90 kilometers gaining us .76 minutes or a little more than 45 seconds. One observation from these values is that Anaheim is the only radar that was able to provide any coverage for the threat as it approaches from the south. Upon further investigation, there is a hill that lies along the 170 line of bearing from LAX on the peninsula that masks the threat until it is almost 5 minutes away. The ranges from adding Radar 1 are seen in Table 8 and are pictured in FIGURE 7.

direction	LAX Range	LAX,1 range	direction	LAX range	LAX,1 range	direction	LAX range	LAX,1 range
000	46.59	46.59	120	46.39	95.65	240	44.27	44.27
010	45.76	45.76	130	44.53	87.61	250	44.73	44.73
020	46.77	46.77	140	42.53	54.91	260	45.01	45.01
030	43.78	43.78	150	45.09	63.67	270	47.78	47.78
040	45.20	53.92	**160**	**21.86**	**47.40**	280	45.36	45.36
050	45.90	66.46	**170**	**17.36**	**19.90**	290	45.82	45.82
060	45.65	75.92	180	44.71	44.71	**300**	**26.54**	**26.54**
070	44.13	78.08	190	46.59	46.59	310	44.63	44.63
080	46.75	96.03	200	45.13	45.13	320	43.97	43.97
090	46.01	74.46	210	42.53	42.53	330	46.32	46.32
100	48.40	100.16	220	42.95	42.95	340	42.23	42.23
110	43.52	84.30	230	42.69	42.69	350	45.01	45.01

Table 8. Reaction Times with LAX and Anaheim Radar(1)

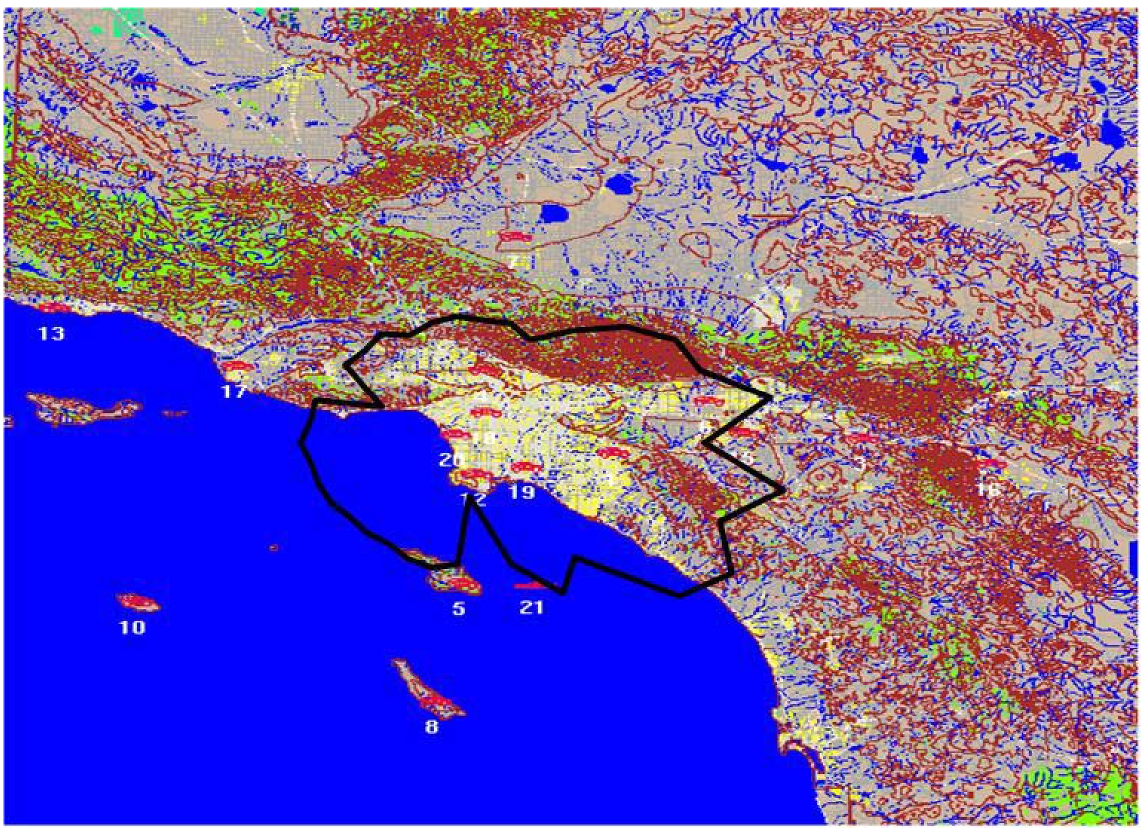

FIGURE 7. LAX and Anaheim Radar (1)

3. Selecting Multiple Radars to Support LAX

While looking at the effects of integrating more than one radar to support air detection in the LA area, many factors were considered. 1) Which radars cover the greatest number of intended routes? 2) Which radars increase the previous low detection ranges? 3) Is there a combination of radars that can be used to greatly increase the reaction time?

a. Which Radars Cover the Greatest Number of Intended Routes?

Many radars placements were able to detect the low slow flyer from multiple attack routes. The radar detection matrix is listed below. By looking at the matrix it is noticed that radars 18 and 19 both detect the threat at almost all routes. This is due to the close proximity that these radars have to LAX. Also of note is that radars 8 and 10 hardly ever detect the threat, this is due to their outlying positions from LAX. Table 9 shows where each radar detects the threat as shown by a shaded and marked X at each bearings.

Radar Placement

ROUTES	LAX	1	3	4	5	6	7	8	10	12	13	15	16	17	18	19
0	X			X			X			X					X	X
10	X			X			X			X					X	X
20	X			X			X			X					X	X
30	X	X		X			X			X					X	X
40	X	X		X			X			X					X	X
50	X	X		X						X					X	X
60	X	X		X						X					X	X
70	X	X		X						X					X	X
80	X	X	X	X		X				X		X	X		X	X
90	X	X	X	X		X				X		X	X		X	X
100	X	X	X	X		X				X		X	X		X	X
110	X	X	X	X		X				X		X	X		X	X
120	X	X	X	X		X				X		X			X	X
130	X	X	X	X		X				X					X	X
140	X	X		X			X			X					X	X
150	X	X								X					X	
160	X	X			X					X					X	
170	X	X			X										X	
180	X			X	X			X							X	X
190	X							X							X	
200	X							X							X	
210	X							X							X	
220	X				X				X							
230	X				X											
240	X								X							
250	X								X	X						
260	X									X				X		
270	X									X				X		
280	X									X	X			X	X	X
290	X			X						X	X			X	X	X
300	X			X						X				X	X	X
310	X			X						X				X	X	X
320	X			X						X				X	X	X
330	X			X						X				X	X	X
340	X			X						X					X	X
350	X			X			X			X					X	X

Table 9. Radar Placement and Detection

b. Which Radars Increase the Previous Low Detection Ranges?

Radars with a close proximity too LAX will not increase the reaction times an extreme amount. As the radar distance increases from LAX the ability to detect the threat from as many routes decreases. The best radars of choice are those that lie somewhere in the middle. For these radars can detect the threats from multiple routes and give LAX a large increase in detection range and reaction time. The individual effects each radar has on detection ranges can be seen below in Table 10.

direction	LAX	LAX,1	LAX,3	LAX,4	LAX,6	LAX,7	LAX,12	LAX,13	LAX,15	LAX,16	LAX,17	LAX,18	LAX,19
000	46.6	46.6	46.6	46.6	46.6	121.5	46.6	46.6	46.6	46.6	46.6	52.9	46.6
010	45.8	45.8	45.8	45.8	45.8	137.5	45.8	45.8	45.8	45.8	45.8	46.8	45.8
020	46.8	46.8	46.8	46.8	46.8	125.8	46.8	46.8	46.8	46.8	46.8	51.3	46.8
030	43.8	43.8	43.8	43.8	43.8	112.9	43.8	43.8	43.8	43.8	43.8	49.8	43.8
040	45.2	53.9	45.2	45.2	45.2	88.1	45.2	45.2	45.2	45.2	45.2	52.6	45.2
050	45.9	66.5	45.9	45.9	65.1	45.9	45.9	45.9	45.9	45.9	45.9	62.7	49.3
060	45.6	75.9	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	61.5	54.3
070	44.1	78.1	44.1	44.1	44.1	44.1	44.1	44.1	44.1	44.1	44.1	58.8	57.0
080	46.8	96.0	147.1	50.5	130.7	46.8	48.9	46.8	126.7	177.0	46.8	56.7	66.3
090	46.0	74.5	174.5	49.2	128.2	46.0	52.8	46.0	108.1	197.4	46.0	57.1	67.4
100	48.4	100.2	155.0	48.4	120.1	48.4	53.9	48.4	140.2	223.1	48.4	55.5	70.2
110	43.5	84.3	147.9	43.5	106.7	43.5	57.0	43.5	108.5	191.5	43.5	53.8	72.5
120	46.4	95.7	162.5	46.4	69.1	46.4	60.6	46.4	109.8	46.4	46.4	50.6	73.0
130	44.5	87.6	150.8	44.5	44.5	44.5	62.0	44.5	44.5	44.5	44.5	48.0	73.9
140	42.5	54.9	42.5	42.5	42.5	88.3	42.5	42.5	42.5	42.5	42.5	52.6	45.3
150	45.1	63.7	45.1	45.1	45.1	45.1	65.2	45.1	45.1	45.1	45.1	45.1	45.1
160	21.9	47.4	21.9	21.9	21.9	21.9	23.6	21.9	21.9	21.9	21.9	23.9	21.9
170	17.4	19.9	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4
180	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7
190	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6	46.6
200	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1
210	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5
220	42.9	42.9	42.9	42.9	42.9	42.9	42.9	42.9	42.9	42.9	42.9	42.9	42.9
230	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7
240	44.3	44.3	44.3	44.3	44.3	44.3	44.3	44.3	44.3	44.3	44.3	44.3	44.3
250	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7	44.7
260	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	78.6	45.0	45.0
270	47.8	47.8	47.8	47.8	47.8	47.8	47.8	47.8	47.8	47.8	107.6	47.8	47.8
280	45.4	45.4	45.4	45.4	45.4	45.4	45.4	150.9	45.4	45.4	121.9	45.4	45.4
290	45.8	45.8	45.8	45.8	45.8	45.8	45.8	162.1	45.8	45.8	123.5	45.8	45.8
300	26.5	26.5	26.5	45.5	26.5	26.5	29.5	26.5	26.5	26.5	117.2	26.5	26.5
310	44.6	44.6	44.6	51.6	44.6	44.6	44.6	44.6	44.6	44.6	106.0	44.6	44.6
320	44.0	44.0	44.0	55.3	44.0	44.0	44.0	44.0	44.0	44.0	91.9	44.0	44.0
330	46.3	46.3	46.3	61.0	46.3	46.3	46.3	46.3	46.3	46.3	71.5	49.8	46.3
340	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2
350	45.0	45.0	45.0	45.0	45.0	109.5	45.0	45.0	45.0	45.0	45.0	51.5	45.0
Average(km)	43.12	54.66	61.52	44.76	52.65	56.12	45.47	49.28	53.18	59.91	56.26	47.04	47.99
Minimum(km)	17.36	19.90	17.36	17.36	17.36	17.36	17.36	17.36	17.36	17.36	17.36	17.36	17.36
React(min)	12.83	16.27	18.31	13.32	15.67	16.70	13.53	14.67	15.83	17.83	16.74	14.00	14.28
time(min)	5.17	5.92	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17

Table 10. Single Radar Advantages to Detection Range (km) and Reaction Times (min)

c. *Is There a Combination of Radars That Can Be Used to Greatly Increase the Reaction Time?*

The best course of action is to use a combination of radars that can be data-linked to one another and share detection information. So we looked at the radars that detected the threat at multiple routes and that gave us the best reaction times without much overlap. This seemed very reasonable except for the routes taken from the sea. There is currently only one radar system from the sea and that is on Catalina Island. Radars 8 and 10 were placed for a what-if scenario. Even if the radars on the islands were in place the radar horizons would still allow for a threat to penetrate near to LAX undetected due to the distances between the islands. Still, there were a few combinations of radars that would be extremely valuable to the reaction time for LAX. These advantages are seen in Table 11.

direction	LAX,1,4,5,8,10,17	LAX,1,3,4,5,7,8,10,17	ALL	LAX,1,3,7,8,10,17	LAX,1,7,17	LAX,1,3,7,17
000	46.59	121.50	121.50	121.50	121.50	121.50
010	45.76	137.52	137.52	137.52	137.52	137.52
020	46.77	125.84	125.84	125.84	125.84	125.84
030	43.78	112.88	112.88	112.88	112.88	112.88
040	53.92	88.05	88.05	88.05	88.05	88.05
050	66.46	66.46	66.46	66.46	66.46	66.46
060	75.92	75.92	75.92	75.92	75.92	75.92
070	78.08	78.08	78.08	78.08	78.08	78.08
080	96.03	147.13	177.02	147.13	96.03	147.13
090	74.46	174.49	197.39	174.49	74.46	174.49
100	100.16	154.99	223.10	154.99	100.16	154.99
110	84.30	147.89	191.51	147.89	84.30	147.89
120	95.65	162.50	162.50	162.50	95.65	162.50
130	87.61	150.76	150.76	150.76	87.61	150.76
140	54.91	88.25	88.25	88.25	88.25	88.25
150	63.67	63.67	65.24	63.67	63.67	63.67
160	47.40	47.40	47.40	47.40	47.40	47.40
170	19.90	19.90	19.90	19.90	19.90	19.90
180	165.99	165.99	165.99	165.99	44.71	44.71
190	162.02	162.02	162.02	162.02	46.59	46.59
200	152.90	152.90	152.90	152.90	45.13	45.13
210	114.78	114.78	114.78	114.78	42.53	42.53
220	111.45	111.45	111.45	111.45	42.95	42.95
230	63.31	63.31	63.31	42.69	42.69	42.69
240	162.42	162.42	162.42	162.42	44.27	44.27
250	160.13	160.13	160.13	160.13	44.73	44.73
260	78.60	78.60	78.60	78.60	78.60	78.60
270	107.57	107.57	107.57	107.57	107.57	107.57
280	121.88	121.88	150.88	121.88	121.88	121.88
290	123.50	123.50	162.06	123.50	123.50	123.50
300	117.17	117.17	117.17	117.17	117.17	117.17
310	106.04	106.04	106.04	106.04	106.04	106.04
320	91.93	91.93	91.93	91.93	91.93	91.93
330	71.54	71.54	71.54	71.54	71.54	71.54
340	45.33	45.33	45.33	42.23	42.23	42.23
350	109.49	109.49	109.49	109.49	109.49	109.49
Average(km)	90.21	111.92	118.41	111.27	80.20	91.30
Minimum(km)	19.90	19.90	19.90	19.90	19.90	19.90
React(min)	26.85	33.31	35.24	33.11	23.87	27.17
time(min)	5.92	5.92	5.92	5.92	5.92	5.92

Table 11.   Radar Combinations and Their Advantages

Table 11 shows that these combinations more than double the average reaction time but they still leave the weakness from the sea. Graphical representation of these radar networks can be seen in FIGURES 8, 9, and 10. Each network continues to show the weakness form the sea, but they have strengthened the original weakness from bearing 300. One thing of note is that FIGURE 10 shows the detection ranges for LAX and all radars networked. This network still has a weakness from the sea. So how can we solve this weakness that exists from the sea?

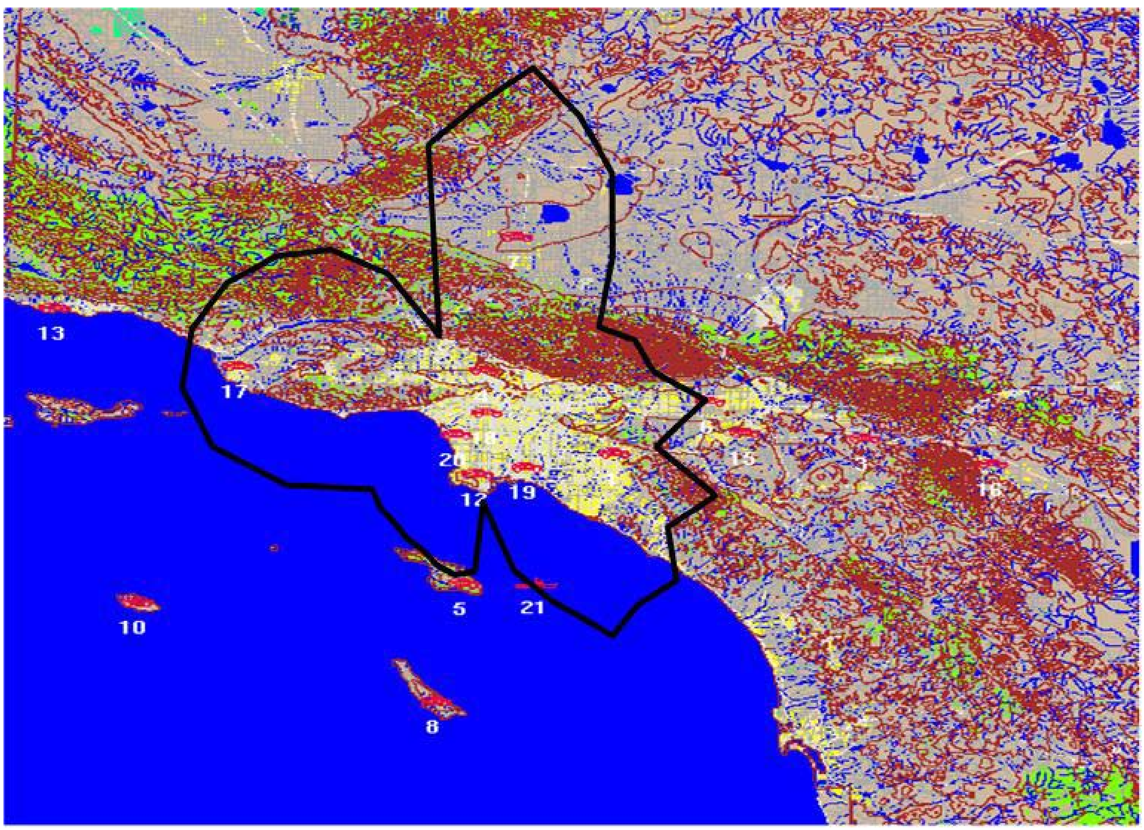

FIGURE 8. LAX with Anaheim, Lancaster, and Oxnard Radars (best viewed in color)

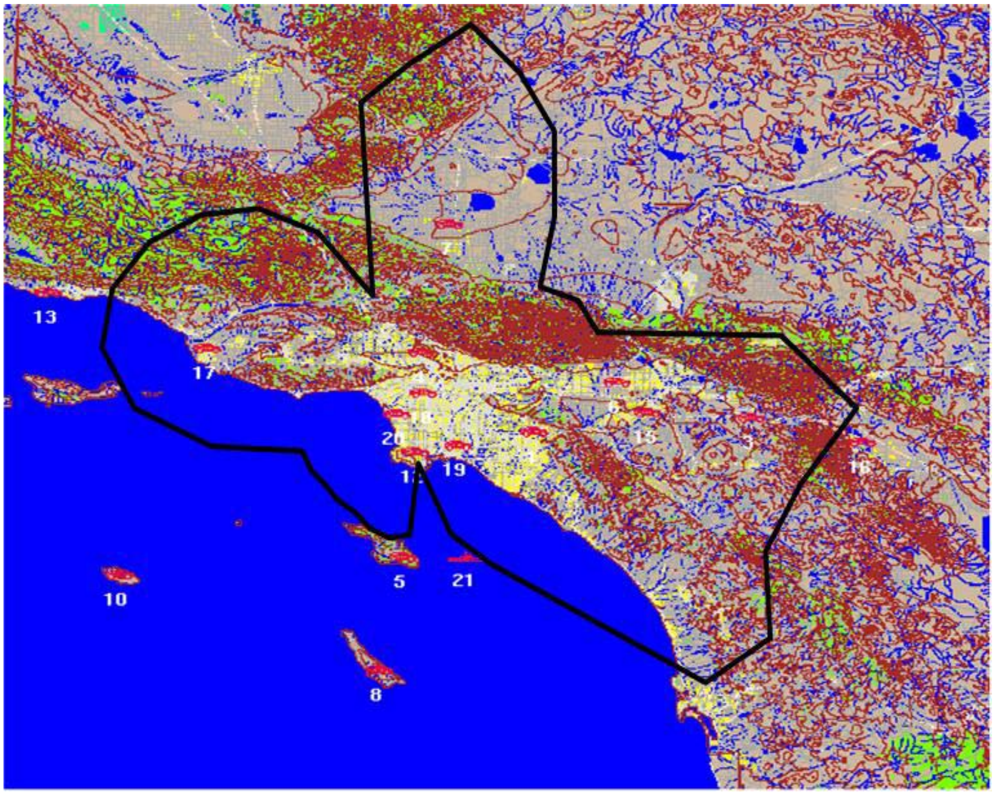

FIGURE 9. LAX and Anaheim, Beaumont, Lancaster, and Oxnard Radars (best viewed in color)

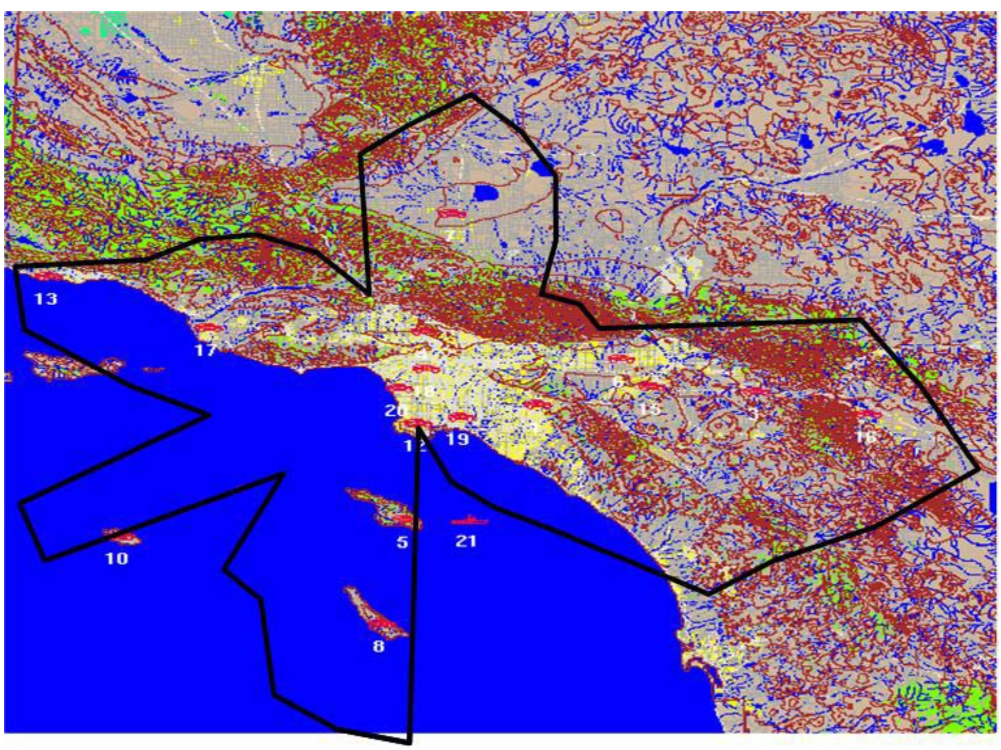

FIGURE 10. Maximum Ranges of LAX with All Radars (Best viewed in color)

4. The Benefits of a Naval Presence

One way to increase the reaction times and detection ranges from the sea would be to add a naval presence. This was done in JCATS by adding a Guided Missile Cruiser at a position along the threat axis where the weakest point of attack is, 170-180 bearings. The reaction times here increased and covered the weakness, as seen in Table 12 and in FIGURE 11. With LAX and only a Navy AEGIS Cruiser, the weakness now becomes the bearing 300 with a reaction time of under 8 minutes.

	LAX,CG			LAX,CG			LAX,CG	
direction	range	React Time	direction	range	React Time	direction	range	React Time
000	46.59	13.87	120	46.39	13.81	240	44.27	13.17
010	45.76	13.62	130	44.53	13.25	250	44.73	13.31
020	46.77	13.92	140	42.53	12.66	260	45.01	13.39
030	43.78	13.03	150	45.09	13.42	270	47.78	14.22
040	45.20	13.45	160	109.63	**32.63**	280	45.36	13.50
050	45.90	13.66	170	110.60	**32.91**	290	45.82	13.64
060	45.65	13.58	180	100.98	**30.05**	300	26.54	7.90
070	44.13	13.13	190	55.34	**16.47**	310	44.63	13.28
080	46.75	13.91	200	45.13	13.43	320	43.97	13.09
090	46.01	13.69	210	42.53	12.66	330	46.32	13.79
100	48.40	14.40	220	42.95	12.78	340	42.23	12.57
110	43.52	12.95	230	42.69	12.70	350	45.01	13.40

Table 12. Detection Data for LAX with AEGIS Cruiser

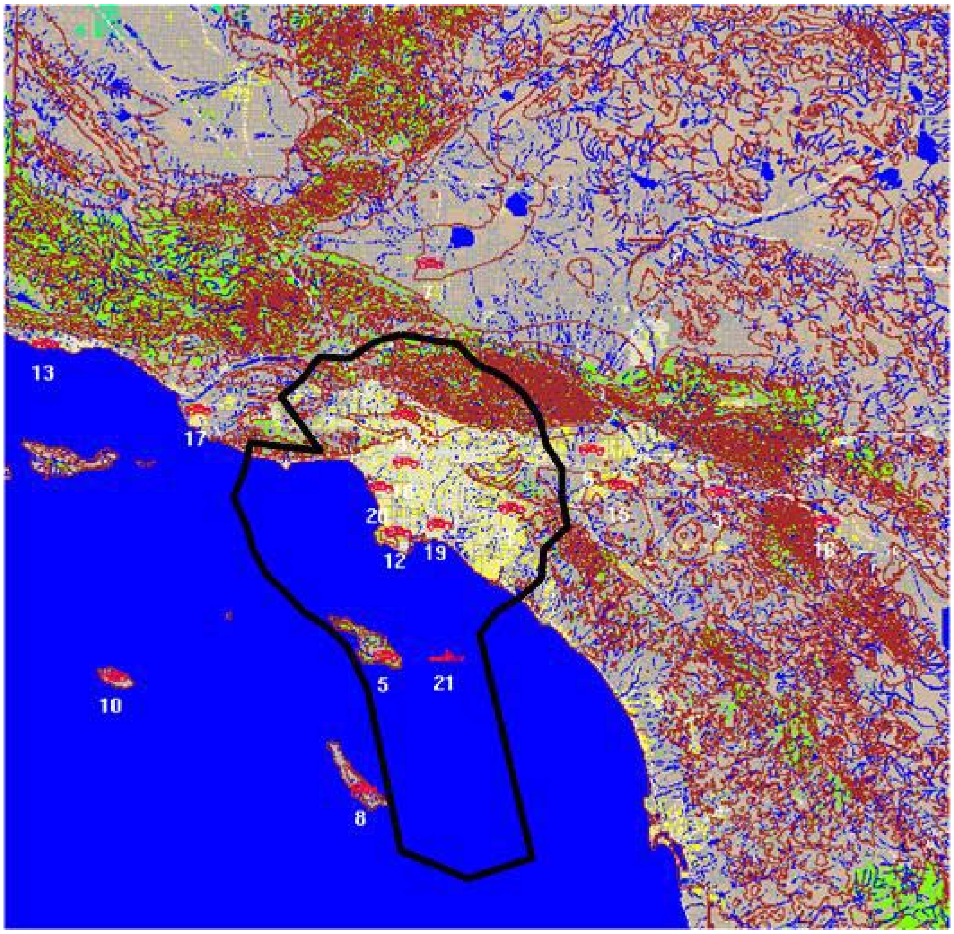

FIGURE 11. Detection Envelope for LAX with AEGIS Cruiser (best viewed in color)

B. SUMMARY

The main detection concern with low slow flyers is that they will be able to arrive on target without being seen by flying below the radar. In the Los Angeles Area there are enough hills and valleys that a threat of this kind will be able to get close enough to LAX to cause damage whether it is detected or not. To detect the threat and to allow enough reaction time for LAX would require more assets than LAX radar alone.

1. LAX as a Single Entity

As a single entity LAX would be able to detect the threat with less than 15 minutes notice at best and only 5 minutes at its weakest point. This is unacceptable for defensive reactions like evacuation and aircraft deployment. LAX needs more radar assets to work in conjunction with it in order to have ample time to react.

2. LAX with One Radar

The addition of one current airport radar to the LAX radar will have minimal effect on both the overall average detection range and the minimum detection range. By networking Radar 3 to the LAX radar, the raction time increases from 13 minutes to 18 minutes. Granted 5 minutes is a lot of time, however this only greatly increased the reaction time from the easterly direction. The other reaction times remained the same. The minimum reaction time also remained constant at 5 minutes.

3. LAX with Multiple Radars

With multiple radars the overall average detection range was greatly affected by the addition of multiple radars. However the minimum detection range remained constant once again. With every radar added to the shared data network, the average reaction time was a little more than 35 minutes, which is a great increase from the average reaction time of LAX by itself, i.e., 13 minutes. Adding 1, 3, 7, and 17 to LAX increases the average reaction time to 27 minutes. This is the most feasible network to build given the radar overlap, the distance each radar is located from LAX, and the coverage area associated with inbound traffic to LAX.

Given the recommended radar network, the weakness from the sea still exists in that the reaction time still remains at 5 minutes. No matter how many of the existing airport radars we connect to the network, the weak spot exists.

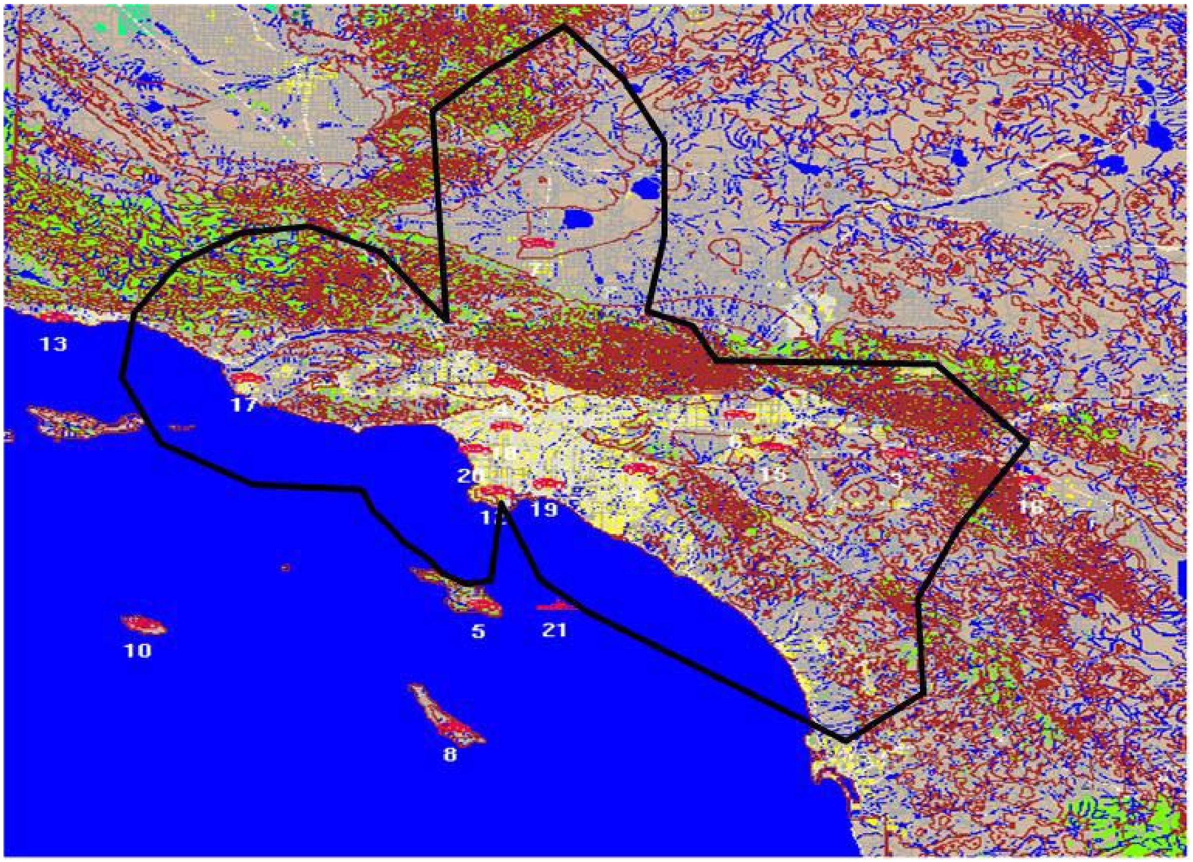

FIGURE 12. Detection Envelope for LAX with Anaheim, Beaumont, Lancaster, Oxnard Radars

4. Benefits of Naval Presence

The benefits of a naval presence to this scenario are great. Due to the overwhelming weakness from the sea, the greatest way to combat this aside from adding a sea based radar system is to position an AEGIS cruiser off the coast. This ship not only allows for early warning but also has a defensive weapons capability not inherent to other radar systems. The increase in reaction time and detection range is noted in the table below, Table 13. FIGURE 11 and Table 12 show the radar coverage gain and that the weakness now lies inland vice seaward as before.

	RANGE		Reaction Time	
	LAX	LAX w/CG	LAX	LAX w/CG
Average	43.13	49.96	12.83	14.87
Minimum	17.36	26.54	5.17	7.90

Table 13. Data Improvement of LAX with AEGIS Cruiser

C. ANALYSIS

The best configuration is to add multiple radars with a cruiser off the coast. This eliminates any weakness in the radar coverage and allows for the greatest reaction time for LAX, which is our high value homeland asset. Our recommended configuration is to have radars LAX, 1, 3, 7, 17 along with a cruiser. Table 14 shows the new detection ranges and reaction times, and it is depicted graphically in FIGURE13.

direction	Range (km)	Time (min)	direction	Range (km)	Time (min)	direction	Range (km)	Time (min)
000	121.50	36.16	120	162.50	48.36	240	44.27	13.17
010	137.52	40.93	130	150.76	44.86	250	44.73	13.31
020	125.84	37.45	140	88.25	26.26	260	78.60	23.39
030	112.88	33.59	150	63.67	18.95	270	107.57	32.01
040	88.05	26.21	160	109.63	32.63	280	121.88	36.27
050	66.46	19.78	170	110.60	32.91	290	123.50	36.75
060	75.92	22.59	180	100.98	30.05	300	117.17	34.87
070	78.08	23.24	190	55.34	16.47	310	106.04	31.56
080	147.13	43.79	200	45.13	13.43	320	91.93	27.36
090	174.49	51.93	210	42.53	12.66	330	71.54	21.29
100	154.99	46.13	220	42.95	12.78	340	42.23	12.57
110	147.89	44.01	230	42.69	12.70	350	109.49	32.58

	Range	Time
Average	97.35	28.97
Minimum	42.23	12.57

Table 14. Ranges and Reaction Times of LAX with Anaheim, Beaumont, Lancaster, Oxnard, and AEGIS Cruiser

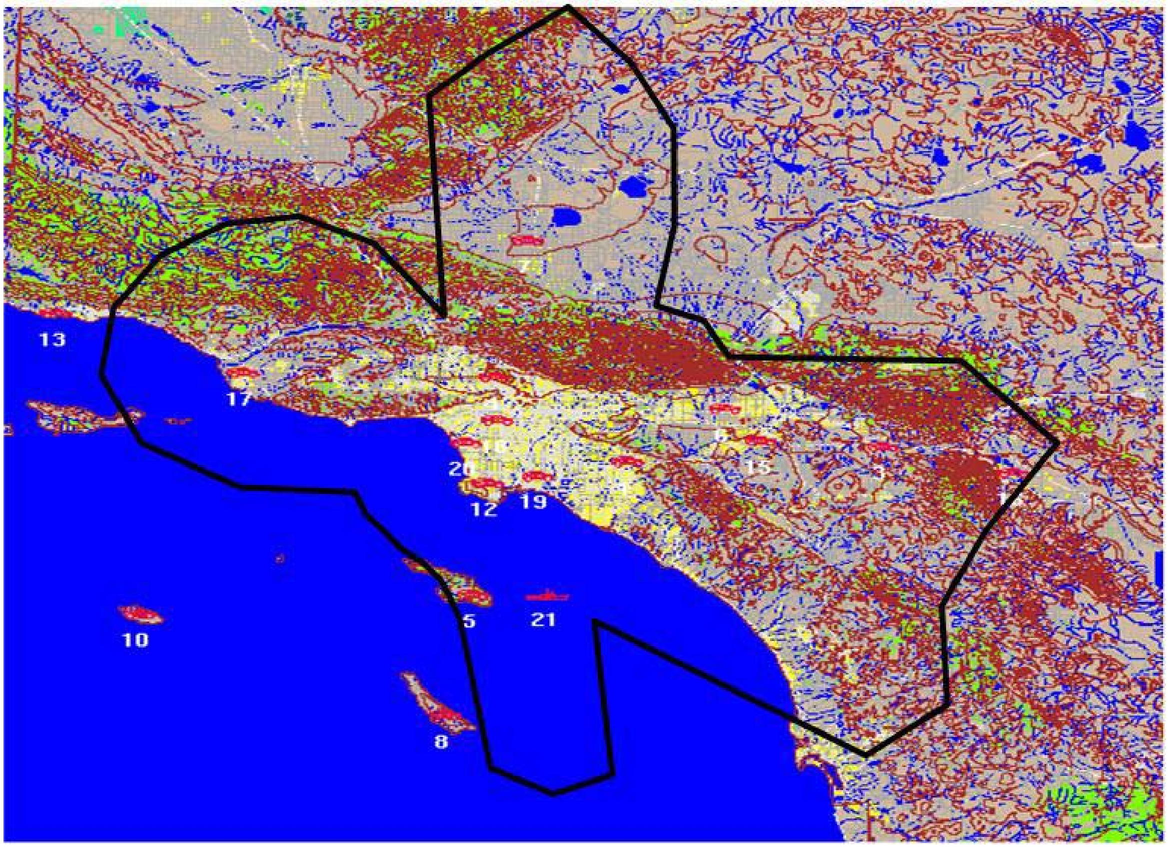

FIGURE 13. Detection Envelope of LAX with Anaheim, Beaumont, Lancaster, Oxnard, and AEGIS Cruiser

VI. CONCLUSIONS AND RECOMMENDATIONS

A. WEAKNESSES

1. From the Sea

Throughout all scenarios ran, this remained the biggest concern from a LSF threat. The threat would be able to close to LAX leaving no more than 5 minutes of reaction time. There are two options to solve this threat problem.

a. Adding a Naval Presence

One would be the addition of a naval presence along the threat bearings 160-200. This would allow for an increase in the reaction time as well as provide a capable means to destroy any threat that approached. This is a reliable weapon against a low slow flyer and would force the threat to attempt an attack along a landward route.

b. Adding Radars On the Islands

There are three main islands off the coast of Los Angeles. These islands could serve as a forward station of a radar system if placed properly, i.e., highest point to allow greatest field of vision. This would require maintenance and man-hours to run them but would give more radar coverage from a weak spot in the defense of Los Angeles.

2. From the North

There also remained a weakness for LAX alone. At bearing 300 a threat would be able to close LAX to within 26 kilometers and only 8 minutes of reaction time before being detected. The threat is able to hide behind a hill from this bearing. If no other radars are added, then a solution here would be to add a separate radar system atop the hill to ensure full coverage is gained from this direction.

B. RECOMMENDED SOLUTIONS FOR WEAKNESSES

1. Naval Presence

No matter how many existing airport radars were chosen to help support the LAX radar detection ranges, there always remained the weakness from the Sea. This weakness was solved with the addition of the Cruiser. The results show that the reaction time was increased and the minimum reaction times went from 5 minutes up to 12 minutes along these critical bearings.

2. Networking Among Radars

Networking the radars also relieved the weakness from the northwest when other radars were able to share contact data with LAX. There was a substantial increase in reaction times when networking between sensors. The minimum reaction time increased from 6 minutes to 35 minutes along the critical route.

3. Incorporating Land Based Radars

Instead of adding a Naval presence to supplement the airport radar systems, land based radars could be added with similar benefits. Strategically positioned land based radars on islands or other land masses could provide an extended detection range without having to utilize Navy assets.

C. FOLLOW ON RESEARCH TOPICS

1. Neutralizing the Threat

Not covered in this thesis is the act of taking the threat out once detected. This potentially has many steps. Communication, Rules Of Engagement, and weapon selection need to be incorporated for this step. This thesis only detected the threat and tried to allow for the greatest reaction time. There may be very different radar choices if the destruction of the threat is the goal due to probability of kill applications.

2. Application To Other Geographic Locations

What makes Los Angeles a good target for a terrorist attack is that there are many mountains and land masses to mask the approach of the threat from many directions. However, without a naval presence the threat can close to within striking distance from the sea no matter how many existing radars are utilized. The principles of this thesis can be applied to other harbors, seaports or cities that a terrorist attack potential exists.

3. Application To Different Threat Types

This thesis is designed to detect a Low Slow Flyer threat to a large urban area. If the threat were faster then the reaction time would lower immensely. A subsonic cruise missile traveling at 550 knots at a low altitude will allow a reaction time equal to 20% of the posted times in this thesis. So, instead of 30 minutes of reaction time LAX would then have 6 minutes. Not only that, but the probability of kill for such a threat would decrease. With any other threat it would be imperative to destroy the threat if it were a faster threat at any altitude. Therefore, a naval presence would be a great advantage to any combating any threat from the sea.

THIS PAGE INTENTIONALLY LEFT BLANK

BIBLIOGRAPHY

1. http://www5.ncdc.noaa.gov/climatenormals/clim20-02/NWS_SNOW_NDYFXX_fmt.dat. Last accessed March 20, 2004.

2. The Joint Conflict and Tactical Simulation (JCATS) Overview Slide Presentation, Tom Mcgrann, Lawrence Livermore National Laboratory, July 9, 2003.

3. Lawrence Livermore National Laboratory, JCATS Simulation Guide, Livermore, CA, 1998.

4. Radar Detected Airplane Before White House Crash, Ruben Castaneda and Pierre Thomas, The Washington Post, September 13, 1994.

5. Support of JCATS limited V and V, James G. Taylor and Beny Neta, September 2001, Naval Post Graduate School.

6. Tampa crash raises serious security questions, , CNN, January 6, 2002. www.cnn.com, last accessed Mar 17, 2004.

7. Terrorist reveals why he choose LAX to bomb, July 6, 2001, Phil Hirschkorn, http://www.cnn.com/2001/LAW/07/05/millennium.plot.trial/. Last accessed 10 mar, 2004.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. CAPTAIN Stanley V. DeGeus
   N76
   Office of Chief of Naval Operations
   Washington, D.C.

4. CAPTAIN Jeff Kline
   Department of Operations Research, Code OR
   Naval Post Graduate School
   Monterey, CA

5. Professor Thomas W. Lucas
   Department of Operations Research, Code OR
   Naval Post Graduate School
   Monterey, CA

6. Lieutenant Colonel Saverio Manago, USA
   Department of Operations Research, Code OR
   Naval Post Graduate School
   Monterey, CA

7. Lieutenant Woodrow M. Nesbitt, Jr
   1310 Kentwood Dr
   Sumter, SC